10/581778
IAP20 Rec'd PCT/PTO 05 JUN 2006
[10537/330]

SOLDER ALLOY, USE OF THE SOLDER ALLOY AND METHOD FOR PROCESSING, PARTICULARLY REPAIRING, WORKPIECES, PARTICULARLY GAS TURBINE COMPONENTS

The present invention relates to a solder alloy as well as a multi-component soldering system. Furthermore, the present invention relates to the use of a solder alloy and of a multi-component soldering system as well as to a method for processing, particularly repairing, workpieces, particularly of gas turbine components.

Gas turbines, as for example aircraft engines or stationary gas turbines, in operation are subject to high mechanical and thermal stress. Thus, during the operation of an aircraft engine, blades, particularly turbine blades, may be damaged by alternating thermal stress and material removal. This results in thermal fatigue cracks and eroded surfaces, which must be completely and reliable repaired when servicing or repairing the aircraft engine. For this purpose, according to the related art, soldering methods are used in addition to welding methods.

In this connection, according to the related art, soldering methods and solder materials are uses as known from U.S. 4,830,934 and U.S. 5,240,491, for example. These soldering methods known from the related art are used for repairing the above damage symptoms and as joining processes in the manufacture of an aircraft engine. Since following the repair, the subassemblies of an aircraft engine are again exposed to high mechanical and thermal stress, it is necessary to provide novel solder alloys and soldering methods.

Using this as a starting point, the present invention is based on the objective of providing a novel solder alloy as well as

a novel multi-component soldering system. The present invention is further based on the objective of providing a use for such a solder alloy and such a multi-component soldering system and a method for processing, particularly repairing, workpieces, particularly gas turbine components.

This objective is achieved by a solder alloy according to Claim 1.

According to the present invention, the solder alloy is a nickel-based alloy and contains at least the following elements: chromium (Cr), cobalt (Co), molybdenum (Mo) and nickel (Ni). The molybdenum (Mo) replaces the tungsten (W) using in the solder alloy according to the related art. By mixed crystal hardening, molybdenum (Mo) indeed increases the strength of the γ-nickel matrix, without, however, disadvantageously increasing the melting point of the solder alloy to the same extent as tungsten (W).

According to an advantageous refinement of the present invention, the solder alloy additionally contains tantalum (Ta), niobium (Nb) and aluminum (Al). This achieves an additional strength by particle hardening effects. Tantalum (Ta), niobium (Nb) and aluminum (Al) are γ'-forming elements.

In this connection, the following composition of the solder alloy is advantageous:

- chromium (Cr) in a proportion of 5 - 17 wt.%,
- cobalt (Co) in a proportion of 8 - 15 wt.%,
- molybdenum (Mo) in a proportion of 1 - 5 wt.%,
- aluminum (Al) in a proportion of 2 - 8 wt.%,
- tantalum (Ta) in a proportion of 1 - 8 wt.%,
- niobium (Nb) in a proportion of 0.1 - 2 wt.%,
- nickel (Ni) in a residual proportion such that the sum of all portions yields 100 wt.%.

According to an advantageous refinement of the present invention, the solder alloy additionally contains palladium (Pd) in a proportion of 0.5 to 5 wt.% and boron (B) in a proportion of 0.5 to 2.5 wt.%.

Palladium (Pd) lowers the melting point of the solder alloy and increases the strength of the γ-nickel matrix by mixed crystal hardening. Furthermore it is advantageous that palladium (Pd) improves the wetting behavior and the fluidity of the molten solder alloy or of the molten multi-component soldering system.

In this connection, the following composition of the solder alloy is advantageous:

- chromium (Cr) in a proportion of 5 - 17 wt.%,
- cobalt (Co) in a proportion of 8 - 15 wt.%,
- molybdenum (Mo) in a proportion of 1 - 5 wt.%,
- aluminum (Al) in a proportion of 2 - 8 wt.%,
- tantalum (Ta) in a proportion of 1 - 8 wt.%,
- niobium (Nb) in a proportion of 0.1 - 2 wt.%,
- palladium (Pd) in a proportion of 0.5 - 5 wt.%,
- boron (B) in a proportion of 0.5 - 2.5 wt.%,
- nickel (Ni) in a residual proportion such that the sum of the portions yields 100 wt.%.

According to an advantageous refinement of the present invention, the solder alloy additionally contains yttrium (Y) in a proportion of 0.1 to 1 wt.% and hafnium (Hf) in a proportion of 1 to 5 wt.%. Like Palladium (Pd), hafnium (Hf) improves the wetting behavior and the fluidity of the molten solder alloy or of the molten multi-component soldering system and increases at the same time the oxidation-resistance of the soldered regions. In order to keep the portion of hafnium-

containing hard phases low, which embrittle the solder structure, the hafnium portion is limited to 5 wt.%.

Like palladium (Pd) and boron (B), yttrium (Y) lowers the melting point or the melting range of the solder alloy such that soldering temperatures can be set specifically in the range of 1200 °C to 1260 °C by the combination of elements Pd-B-Y.

The melting range is defined as the temperature interval between the melting of the first alloy components (solidus point) and the completely liquid state (liquidus point) of the particular alloy.

In this connection, the following composition of the solder alloy is advantageous:

- chromium (Cr) in a proportion of 5 - 17 wt.%,
- cobalt (Co) in a proportion of 8 - 15 wt.%,
- molybdenum (Mo) in a proportion of 1 - 5 wt.%,
- aluminum (Al) in a proportion of 2 - 8 wt.%,
- tantalum (Ta) in a proportion of 1 - 8 wt.%,
- niobium (Nb) in a proportion of 0.1 - 2 wt.%,
- yttrium (Y) in a proportion of 0.1 - 1 wt.%,
- hafnium (Hf) in a proportion of 1 - 5 wt.%,
- palladium (Pd) in a proportion of 0.5 - 5 wt.%,
- boron (B) in a proportion of 0.5 - 2.5 wt.%, and
- nickel (Ni) in a residual proportion such that the sum of all portions yields 100 wt.%.

By alloying silicon (Si) in a proportion of 0.1 to 1 wt.%, the melting point of the solder alloy can be lowered further in combination with the palladium, boron and yttrium.

A particularly preferred solder alloy is defined in Claim 10, its use according to the present invention following from Claim 11.

The multi-component soldering system according to the present invention is defined in Claim 12, and its use according to the present invention is defined in Claim 16.

The method according to the present invention for processing, particularly for repairing, workpieces is characterized by the features of Claim 17.

Preferred further developments of the present invention are revealed by the dependent subclaims and the following description.

The present invention relates to the use of a soldering method for repairing thermodynamically stressed components of a gas turbine, as for example of guide blades of an aircraft engine or also of a stationary gas turbine. The present invention relates not only to the soldering method itself, but rather also to the provision of a novel solder alloy or a novel multi-component soldering system as well as to a use of the solder alloy and the multi-component soldering system. The solder alloy and the multi-component soldering system are suitable both for repairing turbine components, which are manufactured from a polycrystalline alloy, as well as for turbine components that are manufactured from a directedly solidified or monocrystalline alloy. Using the soldering method or solder alloy or multi-component soldering system makes it possible to achieve sufficiently high mechanical properties in the soldered regions of the gas turbine components such as in particular the fatigue-resistances such that the structural integrity of the relevant component of a gas turbine is maintained. Furthermore, improved oxidation

and corrosion properties are achieved in the soldered regions as compared to those regions that are repaired using soldering methods according to the related art.

The new solder alloy according to the present invention is a nickel-based alloy and in addition to nickel (Ni) contains at least also chromium (Cr), cobalt (Co) and molybdenum (Mo). In accordance with the present invention, the tungsten (W) used in solder alloys according to the related art is largely replaced by molybdenum (Mo). This advantageously increases the strength of the repaired region by mixed crystal hardening of the γ-nickel matrix without disadvantageously raising the melting point of the solder alloy.

In addition to nickel (Ni), chromium (Cr), cobalt (Co) and molybdenum (Mo), the solder alloy according to the present invention contains palladium (Pd) as well as yttrium (Y). Both palladium (Pd) as well as yttrium (Y) are advantageous for lowering the melting range of the solder alloy into a range of 1050°C to 1200°C and simultaneously improve the oxidation properties of the solder alloy or of the soldered region. Palladium (Pd) is preferably limited to a maximum portion of 5 wt.% since it makes the solder material much more expensive if it is alloyed in excessively high concentrations.

Another element preferably contained in the solder alloy according to the present invention is boron (B). Like palladium (Pd) and yttrium (Y), boron (B) is advantageous for lowering the melting range of the solder alloy into a range of 1050°C to 1200°C and is limited in accordance with the present invention to a maximum portion of 2.5 wt.%. By limiting boron (B) to a maximum of 2.5 wt.% it is possible effectively to limit the boride phase portion in the soldered regions, which has an embrittling effect.

Furthermore, in accordance with the present invention, the solder alloy according to the present invention contains a suitable proportion of aluminum (Al), tantalum (Ta) and niobium (Nb) in addition to the above-mentioned elements. The portion of aluminum (Al) preferably lies between 2 and 8 wt.%. In the solder alloy according to the present invention, tantalum (Ta) is contained in a proportion of 1 to 8 wt.% and niobium (Nb) in a proportion of 0.1 to 2 wt.%. By alloying γ'-phase-forming elements such as tantalum (Ta), niobium (Nb) and aluminum (Al), additional mechanical strength by particle hardening is achieved in the soldered regions in addition to the already described mixed crystal hardening.

In addition, the solder alloy according to the present invention may contain hafnium (Hf) in a proportion of 1 to 5 wt.%. The use of hafnium has a positive effect on the wetting and flow properties of the molten solder alloy and the oxidation-resistance of the repaired regions of the respective component. The portion of hafnium (Hf) is limited to the specified maximum value of 5 wt.% in order to limit the portion of the hafnium-containing hard phases in the soldered regions, which have an embrittling effect.

In addition, the solder alloy according to the present invention may contain silicon (Si) in a proportion of 0.1 to 1 wt.%. The addition of silicon (Si) is able to support and strengthen the melting point-reducing effect of the palladium (Pd), yttrium (Y) and boron (B), without increasing the boride phase portion in the repaired regions of the component.

According to a preferred exemplary embodiment of the present invention, the solder alloy according to the present invention has the following composition:

chromium (Cr) in a proportion of 5 - 17 wt.%,
cobalt (Co) in a proportion of 8 - 15 wt.%,

molybdenum (Mo) in a proportion of 1 - 5 wt.%,
aluminum (Al) in a proportion of 2 - 8 wt.%,
tantalum (Ta) in a proportion of 1 - 8 wt.%,
niobium (Nb) in a proportion of 0.1 - 2 wt.%,
yttrium (Y) in a proportion of 0.1 - 1 wt.%,
hafnium (Hf) in a proportion of 1 - 5 wt.%,
palladium (Pd) in a proportion of 0.5 - 5 wt.%,
boron (B) in a proportion of 0.5 - 2.5 wt.%,
silicon (Si) in a proportion of 0.1 - 1 wt.%,
nickel (Ni) in a residual proportion such that the sum of the portions yields 100 wt.%.

According to another preferred exemplary embodiment of the present invention, the solder alloy according to the present invention has the following composition:

chromium (Cr) in a proportion of 9 - 11 wt.%,
cobalt (Co) in a proportion of 9 - 11 wt.%,
molybdenum (Mo) in a proportion of 3.5 - 4.5 wt.%,
aluminum (Al) in a proportion of 3.5 - 4.5 wt.%,
tantalum (Ta) in a proportion of 1.5 - 2.5 wt.%,
niobium (Nb) in a proportion of 0.5 - 1.5 wt.%,
yttrium (Y) in a proportion of 0.1 - 0.5 wt.%,
hafnium (Hf) in a proportion of 3.5 - 4.5 wt.%,
palladium (Pd) in a proportion of 3.5 - 4.5 wt.%,
boron (B) in a proportion of 1.5 - 2.0 wt.%,
nickel (Ni) in a residual proportion such that the sum of the portions yields 100 wt.%.

The solder alloy according to the present invention is particularly suitable for use in repairing guide blades of an aircraft engine, the guide blades being made either from a polycrystalline or a directedly solidified or monocrystalline alloy. Following the repair of the relevant regions of the gas turbine using the solder alloy, the soldered regions have mechanical properties that correspond as much as possible to

the material of the undamaged guide blade. The solder alloy is adapted specifically for the purpose of repairing engine components.

The solder alloy according to the present invention has optimized melting properties, flow properties and wetting properties as well an optimized ability to fill cracks.

The effect of the melting point-lowering elements yttrium (Y) and palladium (Pd) on the melting range of the solder alloy is made clear by the following calorimetric measurements.

In the following, four solder alloys A2, A3, A5 and A10 are compared. (For composition see Table 1).

Table 1: Compositions of the solder alloys, concentrations in percentages by weight.

Solder alloy	Ni	Cr	Co	Mo	Al	Ta	Nb	Y	Hf	Pd	B
A2	Bal.	10	10	4	4	2	1	0.5	4	4	1.8
A3	Bal.	10	10	4	4	2	1	0	0	4	1.8
A5	Bal.	10	10	4	4	2	1	0.5	0	0	1.8
A10	Bal.	10	10	4	4	2	1	0	4	0	1.8

Following the melting of the solder alloys in an arc furnace into blocks weighing approximately 10g, specimens of a mass of 50-70 mg were taken from these blocks for the calorimetric measurements. Using DSC (differential scanning calorimetry), the melting behavior of the individual solder alloys was investigated in these specimens. A Netsch DSC 404 unit was used as a calorimeter.

Table 2 shows the solidus and liquidus points of the examined solder alloys A2, A3, A5 and A10 determined by the DSC analysis.

Table 2: Melting Ranges of the Solder Alloys

Solder alloy	T solidus/°C	T liquidus /°C
A2	1059	1196
A3	1010	1254
A5	1039	1249
A10	1068	1244

The solidus and liquidus point listed in Table 2 illustrate the effect, at the basis of the present invention, of the melting point-lowering elements Y and Pd used in addition to the element boron.

Solder alloy A10 has neither Y nor Pd in addition to boron, and accordingly has the highest solidus temperature 1068°C and a liquidus temperature of 1244°C.

Solder alloy A5 contains 0.5 wt.% of Y, but no Pd. Compared to A10, A5 has a clearly reduced solidus temperature of 1039°C, although at 1249°C its liquidus temperature is even somewhat higher than A10.

A similar effect occurs in A3, which contains Pd at 4 wt.%, but no Y.

If Y and Pd are specifically combined as in solder alloy A2, then both the solidus temperature (1059 °C) as well as the liquidus temperature (1196 °C) are clearly reduced as compared to A10. This fact has the consequence that in the case of A2, at 137°C, the melting range as the difference between the liquidus point and the solidus point is lowest in comparison to the other solder alloys. This fact is advantageous to the extent that a low melting range allows for a quick and complete melting of the solder alloy when heated. This prevents a segregation of the melting solder alloy and at the same time ensures an optimum wetting and crack-filling performance.

For this reason, the combination of the two alloy elements yttrium and palladium and their use, in addition to boron, as melting point-reducers in the solder alloy according to the present invention is particularly advantageous.

Up to this point in time, no solder alloy optimized in its composition in this manner is known from the related art.

The soldering temperature of the solder alloy described here is adjusted to the different solution annealing temperatures of the polycrystalline or directedly solidified or monocrystalline alloys.

Furthermore, the present invention provides for a novel multi-component soldering system on the basis of the solder alloy according to the present invention. The novel multi-component soldering system is made up of the solder alloy according to the present invention, as already described above, and additionally of at least one additive material. The multi-component soldering system is obtained by mixing the solder alloy and the additive material, the mixing not having to be limited to the powdery components.

In order to be able to apply the powdery components of the multi-component soldering system onto the regions to be repaired, these components, in accordance with the present invention, are mixed with a binder. The resulting paste is applied with the aid of a sprayer or with the aid of a spatula onto the regions to be repaired. The proportion of the binder in the multi-component soldering system amounts to 1-15 wt% of the powdery components.

The additive materials are metal powders of an alloy, the melting range of which lies above the melting range of the solder alloy. The additive materials may be nickel-based or

cobalt-based alloys. A specific mixing of the solder alloy according to the present invention with the additive materials, a multi-component soldering system is provided, which is especially adapted to a material of a component to be repaired, particularly of a guide blade of a turbine. Accordingly, the multi-component soldering system is made up of a variable powder quantity of the solder alloy having at least one additive material, the mixture ratio of the solder alloy and the additive material being freely selectable. The selection of the suitable mixture ratio is thus the responsibility of the person skilled in the art who is addressed at this point.

Preferred are additive materials, namely, a metal powder, which in addition to nickel (Ni) also contain one or more of the following elements:

chromium (Cr) in a proportion of up to 30 wt.%,
cobalt (Co) in a proportion of up to 20 wt.%,
tungsten (W) in a proportion of up to 15 wt.%,
molybdenum (Mo) in a proportion of up to 10 wt.%,
aluminum (Al) in a proportion of up to 10 wt.%,
tantalum (Ta) in a proportion of up to 10 wt.%,
titanium (Ti) in a proportion of up to 10 wt.%,
rhenium (Re) in a proportion of up to 10 wt.%,
iron (Fe) in a proportion of up to 5 wt.%,
niobium (Nb) in a proportion of up to 5 wt.%,
yttrium (Y) in a proportion of up to 5 wt.%,
hafnium (Hf) in a proportion of up to 5 wt.%,
palladium (Pd) in a proportion of up to 5 wt.%,
carbon (C) in a proportion of up to 1 wt.%,
zirconium (Zr) in a proportion of up to 1 wt.%,
boron (B) in a proportion of up to 1 wt.%,
silicon (Si) in a proportion of up to 1 wt.%.

The additive material preferably has the following composition:

chromium (Cr) in a proportion of 13.7 - 14.3 wt.%,
cobalt (Co) in a proportion of 9 - 10 wt.%,
tungsten (W) in a proportion of 3.7 - 4.3 wt.%,
molybdenum (Mo) in a proportion of 3.7 - 4.3 wt.%,
aluminum (Al) in a proportion of 2.8 - 3.2 wt.%,
titanium (Ti) in a proportion of 4.8 - 5.2 wt.%,
carbon (C) in a proportion of 0.15 - 0.19 wt.%,
zirconium (Zr) in a proportion of 0.03 - 0.1 wt.%,
boron (B) in a proportion of 0.01 - 0.02 wt.%,
nickel (Ni) in a residual proportion such that the sum of the portions yields 100 wt.%.

The mechanical properties of the multi-component soldering systems made up of the solder alloy and the additive material were investigated systematically to ensure that the solder structures in the repaired regions have, on the basis of their static and cyclical strength, a sufficiently high resistance with respect to the thermal and mechanical stresses in the gas turbines.

For this purpose, the following hot tensile tests and fatigue tests (LCF) were conducted.

The tests described here were performed on a select multi-component soldering system, which is characterized by a good melting behavior and a good ability to fill cracks. For this purpose, solder alloy A2 was mixed with an additive material M1 at a mixture ratio of 1:1 (percentage by weight), M1 having the following composition:

chromium (Cr) in a proportion of 13.7 - 14.3 wt.%,
cobalt (Co) in a proportion of 9 - 10 wt.%,
tungsten (W) in a proportion of 3.7 - 4.3 wt.%,
molybdenum (Mo) in a proportion of 3.7 - 4.3 wt.%,

aluminum (Al) in a proportion of 2.8 - 3.2 wt.%,
titanium (Ti) in a proportion of 4.8 - 5.2 wt.%,
carbon (C) in a proportion of 0.15 - 0.19 wt.%,
zirconium (Zr) in a proportion of 0.03 - 0.1 wt.%,
boron (B) in a proportion of 0.01 - 0.02 wt.%,
nickel (Ni) in a residual proportion such that the sum of the portions yields 100 wt.%.

The hot tensile tests were conducted at a temperature of 871°C ±3°C. Using a radiation furnace, the specimens were heated such that a homogeneous temperature distribution was ensured across the entire sample. The tests were conducted in a servohydraulic machine. The extension rate was 0.93 mm/min such that the tests must be classified as displacement-controlled.

Flat tensile specimens from the DS alloy René-142 having a cross section of 6.35 x 1.5 mm and a measurement path of 25.4 mm were used as specimens. The flat specimens were preferred to the round specimens used otherwise since in terms of their dimensions they more closely approximate the case of application, emulating the thin-walled blade of a turbine guide blade having a wall-thickness of 1.5 mm.

In each case, three specimens were tested having traversing soldering gaps of a width of 0.25 mm, 0.5 mm and 1.0 mm, which were soldered or filled up using the described multi-component soldering system A2/M1.

Table 3 shows the averages of the measured hot tensile strengths (UTS) as well as the UTS values of the nickel-based alloys René-80 (polycrystalline) and DS René-142 (directedly solidified) as basic material data.

Table 3: Hot tensile strengths (UTS) of the multi-component soldering system A2/M1 for different gap widths

Soldering system	Gap / mm	UTS / MPa
A2/M1	0.25	643
	0.50	519
	1.00	547
	René - 80	648
	René - 142 DS	858

Table 3 shows that multi-component soldering system A2/M1 has remarkably good hot tensile properties.

For a gap width of 0.25 mm, the measured hot tensile strength (UTS) of A2/M1 corresponds to the value of the base material René-80, which corresponds to a UTS value of 75% of DSR142. Even at a gap width of 0.5 mm and 1.0 mm, 80% (with respect to René-80) or 60% (with respect to René-142) of the hot tensile strength (UTS) are still achieved.

The hot tensile tests provide guide values for the strength properties of the solder structures. The results of the LCF tests are more meaningful since they more closely reflect the actual thermomechanical alternating stress of the gas turbine components.

The test temperature of the LCF tests was 982°C +/-10°C, the flat specimens made of the DS alloy René-142 having been heated inductively. The flat tensile specimens have a cross section of 9.53 x 1.55 mm and a measuring path of 12.7 mm. The test was conducted as an axial, force-controlled tensile threshold test having a sinusoidal stress characteristic. For this purpose, 20 cycles/min at a ratio of stress amplitude/average stress of 0.95 were applied to the specimen.

As in the hot tensile tests, at different maximum stresses, flat specimens were used multi-component soldering system

A2/M1 having three traversing soldering gaps of 0.25 mm, 0.5 mm and 1.0 mm.

The results of the LCF tests are listed as average values in Table 4.

Table 4: LCF data (average values) of the multi-component soldering system A2/M1 for different gap widths and maximum voltages.

Soldering system	Gap width/mm	Max. voltage/MPa	Load changes
A2/M1	0.25	152	50244
		173	6729
		207	4626
		241	702
A2/M1	0.5	152	9146
		173	11785
		241	949
A2/M1	1,0	152	9679
		173	4406
		207	842
		241	454
René - 142 DS		311	13243
		345	7369
		380	2793
		414	1283
René - 80		283	5000
		276	7000
		262	10000
		255	30000

Table 4 shows that multi-component soldering system A2/M1 has remarkably good fatigue properties.

Like the hot tensile tests, the LCF tests show a dependency of the fatigue or tensile threshold strength on the gap width of the solder structures. For a load change number of 5000 cycles as a typical value for LCF tests, the fatigue strength of the A2/M1 solder structures for gap widths of 0.26 mm and 0.5 mm amounts to 65-70% of the value of the René-80 base material or 50-55% of the value of the René-142 base material. For a gap width of 1.0 mm, only a low decline to 60% (with

respect to René-80) or 48% of the fatigue strength of the base material (with respect to René-142) is ascertained.

The fatigue strengths or tensile threshold strengths of multi-components soldering system A2/M1 measured here are clearly higher than the multi-component soldering systems known from the related art.

Using the solder alloy according to the present invention or the multi-component soldering system according to the present invention, a novel method may be provided for processing, preferably repairing, workpieces, that is, for processing guide blades of an aircraft engine. The workpieces may be manufactured from a polycrystalline or directedly solidified or monocrystalline alloy.

The method according to the present invention is based on high-temperature diffusion soldering using the solder alloy according to the present invention or using the multi-component soldering system according to the present invention. This is a repair method. The high-temperature diffusion soldering occurs under the following conditions:

- heating under vacuum or protective gas to a temperature of 1200 - 1260°C with a subsequent holding time of 15 - 60 min,
- cooling under vacuum or protective gas to a temperature of 1100 - 1140°C with a subsequent holding time of approximately 240 min,
- cooling under vacuum or protective gas to a temperature of 1080 - 1120°C with a subsequent holding time of approximately 60 min.

The high-temperature diffusion soldering may be followed by the following heat treatment: Heating under vacuum or protective gas to a temperature of 1065-1093°C with a

subsequent holding time of approximately 240 min, this preferably occurring in the context of a coating process.

Furthermore, the high-temperature diffusion soldering may be followed by the following heat treatment: heating under vacuum or protective gas or ambient atmosphere to a temperature of 871-927°C with a subsequent holding time of 60 - 960 min, this preferably occurring in the context of an aging process.

Of course, the use of the solder alloy and of the multi-component soldering system is not limited to pure repair methods. Rather, the solder alloy according to the present invention and the multi-component soldering system according to the present invention are generally also applicable for joining processes. Due to the mixing ratio of the solder alloy and possibly additive materials optimized for repair purposes, however, the use in the repair of guide blades of an aircraft engine is particularly advantageous.